# DESIGN OF STEEL BRIDGES

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The methods of analyzing a steel structure for the determination of stresses will not be presented in this paper; neither will the methods of analyzing the forces used in designing substructures. We are more concerned about the ordinary conditions confronting county engineers in the large part of their bridge work. The exceptional conditions and large structures usually found in the metropolitan centers of Indiana will not be treated in this discourse. We shall be concerned to a large degree about substructures which are built of concrete of the semi-gravity type; the superstructures which we shall discuss shall have their framework constructed of steel.

The changes in construction methods which have transpired in recent years are favoring some types of construction over other types, e. g., many of our ditches which were formerly constructed by large floating or walking dredges are today being excavated by the light-weight machines mounted on crawler treads which employ a drag line; the bucket of the drag line is easily placed underneath the bridges and readily cleans the channel which otherwise was cleaned by the older type of dredge, thus necessitating the removal of the superstructure.

## Cofferdams

In the design of a steel bridge we may well begin at the bottom and work upward, following the order in which the construction takes place. Many foundation conditions which should not give the contractor any undue worry are often made the source of monetary loss by improper construction of the cofferdam. The use of wood sheeting will never be entirely supplanted by employment of steel sections. In the construction of a cofferdam with wood sheeting, it is important that each pile present a straight edge to its neighbor and that the sheet piles be driven far enough below the bottom of the excavation to retain the unexcavated portions and furnish, insofar as possible, a watertight surface about the excavation. The cribbing which holds the sheeting in place must be of sufficient strength and be properly proportioned to perform its function.

Many specifications in use in Indiana on county work do not say anything concerning the relation between the size of the footing and the size of the cofferdam. If the excavation is in material which does not permit the easy passage of the ground water, such as marl and clay, it may be permissible to allow the deposition of the footing concrete next to the sheeting. However, if a watery pit is encountered, it is well to construct the cofferdam so as to permit the passage of water around the neat lines of the footing to the sump. Gravel and sand formations almost always necessitate the latter type of construction. The construction of a proper sump below the elevation of the bottom of the footings seems to be unattainable by most of our county bridge contractors; just why this should be I do not understand, as one who is experienced in water work will have no difficulty in draining the cofferdam.

### Piling

The location of the struts in the bracing system of a cofferdam should be such as to permit the driving of any foundation piling in the position designated on the plans. It is fortunate for us that we have good native timber in Indiana readily available for use as piling. This state is blessed with hard woods and some good soft woods which are entirely acceptable for use below the water line. An experienced crane operator and rigging crew will facilitate the proper driving of foundation piles; such a crew can easily handle their work with a steam hammer riding free from any guides. It is just as important to know when to stop driving a pile as it is to know when to start. Experience gives us the ability to drive load-bearing piles properly. In the design of a foundation which rests on piling we should not group the piles so closely as to interfere with the individual supporting action of each pile; to err will cause the piles to act as a group; a minimum spacing for piles which support their load by skin friction is about 3 feet on centers. This does not apply to piles which are driven to a stratum which places them in column action. Often an excavation which is comparatively dry before the driving of piling will become a waterhole after the piles have been driven; the same is true vice versa. If it is necessary to pour a concrete seal coat for a foundation supported on piling, the concrete should be stopped several inches below the top of the cut-off in order to permit the remainder of the footing to bond on the projecting butts.

### Foundations

There are many types of foundations; but those with which we are generally concerned in Indiana are steel cylinders, frame or trestle abutments, wing abutments, U abutments, and counterforted abutments. In addition to these types we sometimes use concrete pile trestle bents with a concrete cap. In selecting the type of foundation there are numerous things to consider, such as cost, type of fill, high water elevation, and various other factors.

The use of steel cylinders is not as common today as it was 20 and 30 years ago. Each end of the load-bearing frame is supported on a steel cylinder made up of plates $\frac{1}{4}$ to $\frac{3}{8}$ of an inch in thickness; a cluster of piles is usually driven within the excavated cylinder, which is then filled with concrete. In order to retain the roadway fill, steel plates supported by transverse beams are placed between the cylinders. Steel cylinder foundation construction entails considerable maintenance expense in painting; this type of construction is not readily adapted to effective design of wings for the abutments.

The frame or trestle abutment constructed of concrete should be more widely used than we find it today, as it is economical and lends itself to rapid completion and is quite satisfactory when the cost of increasing the length of the bridge is less than the cost of retaining the fill of the approaches. Pier construction of this type should be more widely employed than we now find it.

The wing type of abutment is generally of the semi-reinforced cantilever design, obtaining its stability by its own weight and by the weight of the fill which it is retaining. The wings are constructed at an angle with the abutment proper or are a continuation of the abutment below the mud wall. In this type of construction we generally find the maximum soil pressure at the edge of the footing next to the stream; if the footing is piles, the groupings of the piling will be closer at this location. This type of construction is seldom economical for heights exceeding 25 feet. The form work costs per cubic yard of concrete in place are less for this type of concrete abutment than for any other design in concrete.

The design of U abutments is usually economical in heights exceeding 25 feet. One of the advantages of this type of construction is that the roadway fill which is being retained assists in reducing the overturning moment on the abutment proper by lending its weight and friction to holding the wings of the U, which are constructed monolithically with the abutment proper. Step footings may be used to reduce the excavation. The wing walls are tied together by concrete beams which pass horizontally through the fill. Obviously this type of construction which employs tie beams cannot be used economically for roadway widths exceeding 25 feet.

Counterforted abutments are usually economical in heights above 20 feet. This type of construction contains less concrete than the semi-gravity type and utilizes the roadway fill to assist its stability against the overturning forces.

In the selection of the type of abutment we must not lose sight of the fact that as soon as the quantity of concrete is reduced, the cost of the form work is increased, and that thin sections are highly reinforced and prohibit thereby the easy deposition of concrete in them. Every time that the direction of a plane surface is changed, the cost of the form work is increased. Heavily reinforced sections increase the cost of placing the reinforcing steel. Intricate formwork reduces the salvage value of the dressed lumber. Inspection of heavily reinforced concrete work requires a more experienced class of inspectors than semi-reinforced work. Abutments should be designed to withstand all the forces acting upon them and should be stable without the load of the superstructure. Abutment construction of a highly reinforced nature should have all construction joints correctly placed; the reinforcing steel should be of such lengths as to develop its tensile strength by bond or by hooks. Construction joints which are located so as to receive shearing stresses must be provided with key ways of sufficient size and shape to transfer the shearing and bearing stresses.

### Superstructure

**General.** In the selection of a superstructure there are numerous factors which have an influence upon the type to be used. We should always bear in mind that the number and shape of the spans is important from an artistic viewpoint. While it may at times be economical to mix up the types in the same bridge, yet this arrangement may not present the best appearance to the eye of the layman, and as a result such a bridge would bring criticism to the steel industry at large. Insofar as possible an odd number of spans is preferable to an even number of spans; while this is the same rule which we apply to the construction of multiple span arch bridges, it is not necessary to adhere to it as rigidly as we do for the former. Some of the factors which may have a determining influence upon the superstructure selection are the nature of the traffic with respect to loads and frequency, the differential between the roadway and highwater, the aesthetic requirements as suggested by the location, the length of the bridge, the floor material, maintenance possibilities, erection difficulties, the kind of stream, whether dredge ditch or natural channel, skew angle if any, conditions affecting transportation, cost, and the time element.

If the live loads to which the bridge will be subjected are not sufficiently large to require the superstructure to have a strength equal to that of the bridges which are known to receive heavy loads, then we may be justified in building a light superstructure. The frequency with which the bridge is used by traffic will have a bearing upon the floor materials and the roadway width. The difference between the elevation of the roadway and the elevation of highwater will sometimes decide for us whether we are to have a deck structure or a through structure. In selecting a superstructure we should endeavor to fit the proposed work to its surroundings insofar as possible. This often means that steel should be encased in concrete; it sometimes means that a truss should be eliminated from consideration. The over-all length of the bridge will generally determine the number and location of the spans, provided that the main water channel is not in an odd location. The position of railroads and streets influences the span lengths of all overhead structures. The selection of the floor material sometimes has a direct bearing upon the type of superstructure.

All steel structures which have their framework exposed to the elements require periodic maintenance, and such maintenance should be reduced to the minimum by correct fabrication and erection. If hanging scaffolds will be required for maintenance painting, we may rest assured that our structure will not have any more paint than the law allows after it is erected. No engineer will neglect the importance of the difficulties which are presented in the field for the erection crew. High falsework framing, driving of piling in swift currents, the location of sills on rock beds, the settlement of piling through rubble fills, continued and frequent high-water stages of the stream, driftwood, the scarcity of good falsework timbers, soft and unstable stream beds, and various other items should be considered by the engineer who is selecting the superstructure.

It is sometimes important that we do not use the same type of superstructure over a dredged ditch as we would use over a natural channel. The skew angle to which the superstructure must be fabricated is important. A truss bridge should be skewed panel point distance, as it is not economical to attempt to place the end floor beams at other than a panel point; the location of stiffener angles on the plate girder is often determined by the skew angle; we should bear in mind that the transfer of wind stresses to the abutments is not as direct in a skewed structure as in a square structure, although this does not hold as much importance for highway bridges as for railroad structures. Transportation facilities may be such as to make it impracticable to use a plate girder. The relation which the cost of our superstructure bears to the cost of the project needs no explanation. Sometimes the time element enters into consideration, as some types of superstructure lend themselves to more rapid construction than other types; since the highways are financed by the public, the interests of the latter are in their continued use.

Regardless of the type of superstructure which the engineer selects, we shall have such points to take care of as expansion and contraction, the protection of roller nests or shoes or rockers, and the camber of the structure as a whole. Roller nests are generally used to transmit the bearing to the abutments for structures of about 150-foot spans and over. The use of rockers for expansion ends is economical with spans of about 80 feet to 150 feet; plain bearing plates for the expansion ends may be used for spans less than 80 feet. In this third type of bearing we do not use pins in the end panel points. The roller nests may consist of segmental or complete rollers; in any event they should be large enough and so held in place and protected from exterior influences as to permit the proper performance of their function. In placing segmental rollers and rockers it is well that we consider the relation between their angular position and the temperature.

All other items being equal we should not select multiple span construction instead of one or two large spans unless we find that the over-all cost of the bridge, including the several foundations, does not exceed that of the single or double span with its fewer foundations. The number and lengths of the spans may be influenced by the United States War Department if the bridge is located over a navigable stream.

Any superstructure should be designed for all the loads to which it will be subjected. The load of the bridge itself, that is, the weight of the frame work, the floor system, and the floor slab, is called the dead load. The live load consists of the loads brought upon it by the traffic which uses it and by snow and ice. The traffic live load may be distributed or concentrated; the structure as a whole and its several members will be designed so as to make the whole no stronger than its several parts. The impact to which a structure is subjected by moving loads is of importance; the more smooth the approach to the structure and the more smooth the wearing surface of the floor, the less will be the impact which the structure receives. Traffic passing from a concrete road slab to a concrete floor slab in the same plane causes little impact on the superstructure. However, if the same traffic may be leaving a gravel road and entering a floor slab not in the same plane, it will give a considerable impact to the floor system.

The fabrication of steel superstructures should be such as to permit a camber in each span; this will allow for the sag in the superstructure incident to the application of the dead loads. This camber cannot be put into the steel work by jacking up the floor beams or any other method in the field. No camber can be placed in a span consisting of rolled beams, but the optical illusion of sag in a perfectly level span may be eliminated by the use of a properly proportional concrete curb and handrail.

The detailing of the several members of a steel superstructure conforms to the best practice when locations for extraneous deposits are eliminated insofar as possible.

We should see in the near future an increased use of the so-called cement gun in the application of a coat of encasing concrete about steel members such as plate girders and rolled beams. The use of the cement gun will increase as soon as we find them more widely distributed.

**Plate Girder.** The plate girder may be either deck, half through, or through. If it is deck, we shall have to provide a handrail. For the ordinary loads which we have in Indiana the plate girder is seldom economical for spans less than 75 or 80 feet in length unless the girders are encased in concrete. Usually we find after an analysis that we do not need cover plates on the flanges if the girders are to be plain and of a length between 60 and 80 feet. It is doubtful if good practice is followed when we do not use a top cover plate to protect the top of the girder from the elements. The web plate thickness of the girder should be a minimum of 5/16 inch. As plate girders are generally shipped in a single piece they are difficult to handle in loading and unloading with as small a crew as can handle some other types of superstructures very easily. Seldom if ever do we find on the average county job a crane of sufficient load capacity to handle a setting of a plate girder. It is usually necessary to erect falsework and roll the girder out to its position. Some engineers will not permit the handling of a girder in any position except the upright. It is well to make a cost estimate for a plate girder design for roadways exceeding 24 feet in width.

**Rolled Beams.** Since the advent of the wide-flanged rolled beams, sometimes called girder beams, we have seen their use increase from year to year as the sections have increased. The design of such beams by the steel companies so as to permit the section modulus to increase in proportion to the increase in weight of the section has facilitated the use of the side-flange section by the bridge designer. Spans which consist of rolled beams do not take much more headroom than the better designs of trusses and plate girders; the erection costs are low, they lend themselves to architectural treatment, the fabrication costs are much lower than those of the plate girder and truss, and the maintenance should not be as much as those of the former two types. Other things being equal, we can design a span today using rolled beams with concrete floor slab for less money than the truss and plate girder provided the span does not exceed 60 feet and provided the roadway width is 24 feet or over. We are also designing rolled beam spans with concrete floor slabs which are cheaper than rolled beam spans with wood subfloor and a wood block or plank wearing course, provided the span length is around 30 feet or more.

When the span length for the rolled beam bridge is about 36 to 40 feet, it is well to introduce diaphragms, in the nature of standard section I-beams at the third points of the span, to add rigidity to the deck. If all of the beams are encased in concrete, the above-mentioned diaphragms may be omitted. Formwork for the concrete encasement of steel beams does not require any falsework as the forms can be suspended by pencil rods passed over the top flange and threaded at the ends to receive washers and nuts, the rods passing through holes in the formwork. If an architectural treatment of the fascia girders is desired, paneling may be introduced in the formwork. When the steel is encased in concrete, it does not require any paint. Field connections of the diaphragms to the webs may be bolted, and thus a compressor and riveting tools are dispensed with. If the beams are encased in concrete, the concrete should be figured in the dead load. An 18-inch beam with a 7½-inch flange spanning a length of 30 feet will require an increase in its section modulus of about 18 per cent to carry the additional load required by encasing it with concrete of a rectangular cross-section larger than the beam at all points by 2 inches at least. Likewise a 36-inch beam with a 12-inch flange will require an increase in its section modulus of about 35 per cent for a similar encasement.

One job which demonstrated the practicability and economy of using encased rolled beam sections was the widening of an 80-foot arch span on each side by placing concrete piles in the middle of the span and spanning the waterway with rolled beams encased in concrete and supporting a concrete hand-rail; the end reactions were obtained by pile construction, and the roadway slab over the fill was supported by the cantilevered ends of the beams; this structure was over a quiet waterway about 8 feet in depth; no falsework was necessary and the two sides were widened with permanent construction, requiring no maintenance, for the price which would have been paid an engineer for designing a new arch bridge.

**High Truss.** The field of the high truss is the same today in Indiana as it has been in the past with reference to other types of steel superstructures. No one will question the advisability of using a through truss on spans of 125 feet and over for ordinary construction requirements such as we have to contend with in this state. We have been rather fortunate in the past to have had structural shops of such intelligence and integrity in this locality that we have not suffered from faulty design and fabrication of our large span through trusses.

## Cost Comparisons

The following figures have been obtained from an actual design. The clear span required was 80 feet, with a 20-foot clear roadway and one 5-foot sidewalk. The live load was a concentrated 20-ton truck or a uniform load of 100 pounds per square foot. The location required that a structure pleasing to the eye and of low maintenance cost be designed. Using rolled beams of 2 spans, each 40 feet clear, a concrete floor and walk, concrete hand rails, encased fascia girders paneled and simulating a flat arch with a springing line, we will take the cost as unity, which cost includes that of the pier. This same location spanned by a single pony truss bridge with concrete walk and slab and steel handrail would have cost 1.07. If a single span plate girder, with the girders entirely encased in concrete, the floor system not encased, had been used, the probable cost of the superstructure would have been represented by 1.40. If the total cost of the rolled beam bridge is taken as unity, then the total cost of the pony truss with its two foundations would be 1.06, and that of the plate girder with its two foundations would be 1.27.

Another cost estimate for a superstructure of 24-foot clear roadway, 30-foot clear span, 20-ton truck loading was made. Using rolled beams, reinforced concrete floor and concrete handrails, none of the beams being encased, we assume cost as unity. These same conditions can be fulfilled by a pony truss with long leaf yellow pine 3-inch creosoted plank, 12-pound treatment, sub-floor, and a one-inch asphalt plank wearing surface for a price of 1.03. The same conditions can be fulfilled by rolled beams, same wood and plank floor, heavy lattice hand rails, for a cost of 1.28. This bridge is located about 125 miles from a creosoting plant, 50 miles from a steel company, and within 20 miles of a gravel supply. These costs are for the year of 1930.

### Conclusion

The counties of this state are today building sturdier bridges and more enduring structures than have been built in the past. This paper is not a symposium for the designing engineer who is entrusted with the complicated analysis attendant upon an economical design; if only the surface is scratched and we as a body are brought to a more keen realization of the importance of our function as bridge engineers as well as highway engineers, this paper will have accomplished its aim.

## IMPROVEMENT OF CONTRACTING PRACTICE

By W. M. Holland, Executive Secretary, Indiana Highway Constructors, Inc.

Let it be understood that Professor Petty did me no favor when he invited me last evening to "pinch hit" on this subject for Ward P. Christie, now of Ulen & Company, Lebanon, Indiana, and formerly research engineer for the Associated General Contractors of America. While with the A. G. C. of A. the very nature of Mr. Christie's work carried him into close touch with existing practices in the field of contracting and with the development of improvements therein. It should be stated in fairness to him that some of our present practices